Smart municipal energy grid within electricity market

Conference Paper · June 2016

3 authors:

Ilija Batas Bjelic
University of Belgrade

Nikola Rajaković
University of Belgrade

Neven Duic
University of Zagreb

This is a preprint of the article: **I. Batas-Bjelic, N. Rajakovic, and N. Duic, "Smart municipal energy grid within electricity market," presented at the Proceedings of the 2nd South East European Conference on Sustainable Development of Energy, Water and Environment Systems, Piran, 2016.**

Smart municipal energy grid within electricity market

Ilija Batas-Bjelic*, Nikola Rajakovic
Department of Power Systems, School of Electrical Engineering, University of Belgrade, Serbia
e–mail: Batas@etf.rs, Rajakovic@etf.rs

Neven Duic
Faculty of Mechanical Engineering and Naval Architecture
University of Zagreb, Zagreb, Croatia
e–mail: Neven.Duic@fsb.hr

ABSTRACT

A smart municipal energy grid including electricity and heat production infrastructure and electricity demand response has been modelled in HOMER case study with goal to decrease total community yearly energy costs. The optimal configuration and sizing, with minimal costs, have been presented and compared using scenarios. Smart municipal energy grids will have an important role in future electricity markets. Their flexibility as participants in electricity markets is increased with possibility to utilize excess electricity production from CHP and variable renewable energy sources through heat storage. The costs and technical, economical and environmental benefits of smart municipal energy grids will be discussed followed with conclusion.

KEYWORDS

Smart grid, demand response, district heating, real time pricing.

INTRODUCTION

Future energy systems are in transition towards increased flexibility in operation which will bring the economic benefits [1]. The decentralized smart multi-energy systems [2, 3] with demand response as locally available flexibility option [4] helps that these energy systems of future become more efficient, environmentally friendly and reliable [5]. Reliability will be more and more important as a today number of catastrophic events e.g. floods will increase in future [6] and increase the need for more resilient smart municipal grids [7].

Possible smart isolated grid configuration with demand response and biogas combined heat and power plant has economic benefits thanks to its flexibility which is proven by using Hybrid Optimization of Multiple Energy Resources (HOMER) simulation tool [8]. An intermittency friendly system with heat/cold demand and storage and with trading electricity on the spot market has been shown for a different energy carrier prices in study [9]. The smart municipal energy grid design and economics response to the governmental constraints has been shown using HOMER in [10].

* Corresponding author

In the article [11] a flexibility of heat and electricity provision from the biomass plants has been accessed for Germany but not for the case of Republic of Serbia, therefore one case study on City of Sabac will be elaborated. A technical feasibility study including techno-economic analysis of combined heat and power plant fuelled with biogas has been for plant "Voganj" in Ruma, Serbia [12]. The problem of excess electricity and heat has been solved with grid connection and food production nearby. The technical details about grid connection of the small biogas plant are known from similar pilot project in the region [13].

The economics of energy production depends significantly on the yearly utilization. For heat production only it is hard to run units for more than 2,500–3,000 hours per year [14] therefore utilization should be increased selling the energy to the national grid within feed in tariff scheme [12, 15, 16] or participating at electricity markets. The specific investment costs for the CHP plant based on biogas engine vary with the plant size 800-9,000 €/kW_{el} [17-19]. More precisely they can be estimated for each size using formula from [20]. The operation and maintenance (O&M) costs are depending on gas quality 0.01-0.02 €/hour*kW for the liquid gas engine [21]. They also may be estimated from formula in [20]. Resulting marginal cost of heat production varies 3.4-6.6, from waste/crops, and for natural gas 3.6 c€/kWh [22]. Average cost of electricity produced from biogas CHP plant are calculated to 13c€/kWh_{el} in [12]. The price of the input feedstock including transport varies from 0-175 €/t feedstock [18], for poultry, 2.5 for pig manure, energy maize 38-68 [16] and food waste of 40€/t [23]. The net costs can be calculated by subtracting the feed in premium from these cost. Therefore for the community a feedstock cost may also become negative [23], but this could enact a synergetic effect between agriculture and electricity from renewable energy [13]. Natural gas price of 0.3-0.4 €/Nm3 for the small consumer and 0.2- 0.1 €/Nm3 at connection to the gas transport network for Republic of Serbia have been assumed. Internal rate of return (IRR) of 6.92, with payback period is almost 11 years discount rate (8%) has been found in study for the CHP plant in Republic of Serbia [14]. In another study [12] also for Republic of Serbia payback period of 9.8-11 years for electricity only with feed in tariff, and 4.6 years for electricity and heat sold, but with 15-20% interest ratio, has been calculated.

The lower heating value (LHV) of biogas varies 12.6 - 22 MJ/kg [16, 24]. The gasification ration varies from 0.2 [t/t] from energetic crops [25] to 0.7 from manure, assuming a 0.5 as an average [26]. The carbon content of a biogas varies from 25%-45% [16, 19, 24]. Based on emission factors for different energy sources [19] and equipment [26], emission constrained dispatch might be done in HOMER with respect to the environmental constraints.

Currently, the district heating in Serbia is dominantly based on fossil fuel only-heat boilers: natural gas (61%), lignite/coal (20%) and fuel oil (18%) and there are no renewable district heating grids in Serbia. There were two energy licences for the biomass cogeneration given in the municipalities Prijepolje and Cajetina. There are about 100 MW of biomass cogeneration with 640 GWh_{el}/a of electricity production envisaged with the National renewable energy action plan [27]. According to this plan the envisaged share of biomass cogeneration in district heating and cooling amounts to 33% of heat energy produced from additionally commissioned facilities (2009-2020), or around 570 GWh_{th}/a. According to the Law on privileged producer the feed-in tariffs (8.22-13.26 c€/KWh) are available for the electricity production from biomass but nor for heat energy nor for cogeneration. Also, support schemes such as feed-in tariff for the renewable district heating and cooling lies on the responsibility of the municipalities, by the Law. On the other hand the positive economic outlook should be expected for the rural communities. These communities should benefit economically from the localization of the heating and cooling supply chain, but also from the food industry that has significant demand for heating in the winter and cooling during summer months banded into smart municipal energy grid. The case study community, the City of Sabac, has a district heating utility named "Toplana-Sabac" with a capacity of 72.3 MW. The heat production is manly based on natural gas (93% of capacity) and small part on fuel oil (7%). The system supply is the heat for about 6,700 customers in households and 600 in commercial sector.

The case study should include biomass district heating/cooling demand for around 450 households and 800 kW in other sectors. Most of the economic studies are based on simplification of an assumed utilization ratio of the biogas, natural gas plants and a feed in contract to sell at agreed electricity price [14, 22]. Utilization ratio is a bit less due to load management in smart municipal grid [24]. In this article this has been tested in a hourly simulation of distributed generators economic dispatch under real time prices for Republic of Serbia, using biogas plant as a load management unit, in the case of City of Sabac. The result is decrease in operation of those generators but similar payback times due to decreased interest rates.

Homer study [28]

METHOD

The Hybrid Optimization of Multiple Energy Resources (HOMER) simulation tool has been used for the modelling and assessment of smart municipal energy grid configurations. This is very used tool for simulations of integration of variable renewable energy sources [29], well documented [30, 31] and with useful help file. The tool has been used in vast of techno-economic studies for grid connected and islanded operated systems e.g. [8, 10, 32-39].

In the study [34] HOMER has been compared to the EnergyPLAN and other self-build tool for assessment of demand response, but without consideration of variable renewable energy sources and heat demand. High profitability in the case of smart isolated energy grid based on renewable generation, demand response and biogas CHP plant has been presented in the case of Congo [8]. The HOMER has been used as a planning tool for municipal smart energy grids in Serbia for the purpose of Covenant of Mayors optimal local energy plan [10], but with fixed national electricity grid tariff and not real time electricity market prices. For more precision in modelling of physical electricity grid HOMER may be soft-linked with PowerWorld tool like in [32]. HOMER might be used to model a smaller smart household energy systems like in [40], heat demand was not accessed but only electricity demand. HOMER has been used for modelling of a pumped hydro storage power plant [41] therefore will be useful in future to access demand response potential of water pups for advanced agriculture in state district Macva around City of Sabac.

In the distributed generation optimal operation algorithm weekly simulations with respect to detailed generator efficiency modelling and peak demand minimization of an industrial grid might be found in [42]. Using EnergyPLAN and Matlab it has been shown [16] that pit storage has economic advantage over biomass power plant for the peak shaving.

Case study City of Sabac

For the case study of smart municipal energy grid City of Sabac was selected because its significance to the research project, but any municipality or city in Republic of Serbia, or in the region, may be considered for the future case studies. It has been assumed that a small community consisting of 450 households with heat and electricity demand and industry with a heating/cooling demand of 800 kW shall be supplied during one year. Configuration of the smart municipal energy system has been shown at Fig. 1.

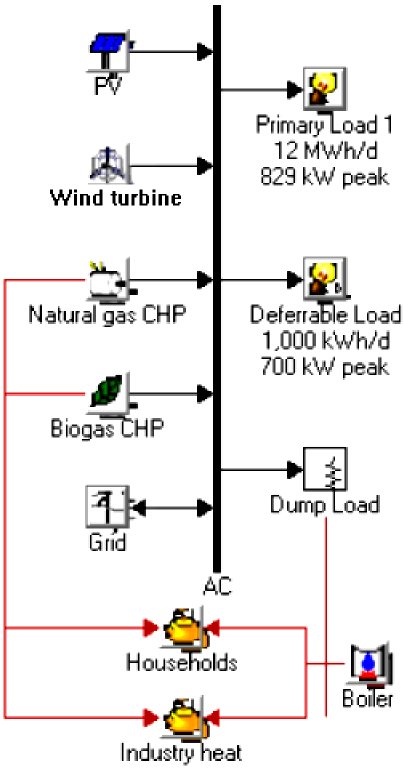

Figure 1 Smart municipal energy grid configuration: PV, Wind turbine, Natural gas CHP generator, Biogas CHP generator, Thermal load: Households, Industry, Primary and deferrable electricity load,

All houses and industry is connected to the national electricity grid and assumption of a district heating grid and the boiler using natural gas has been assumed. The electricity load is divided to deferable and non-deferable (primary) load. Possible investment options are CHP plant based on biogas or natural gas, photovoltaic (PV) and wind power plants. Also, option of converting electricity to heat as a dump load has been assumed.

Demand. For the heat demand a community with average household of 100m^2 and 150 kWh$_{heat}$ demand has been assumed resulting in total household demand of 18,480 kWh$_{heat}$ /day. The sensitivity analysis might be done for other consumption per year. The heat duration curve has been obtained using degree-day method and average year temperature. Additionally, besides heat demand, hot water demand may be also considered in future work [24]. For the industrial heat/cold demand an assumption on 24 working hours 5 days a week during 53 weeks with constant demand of 800 kW with random day-to-day variability of 10% and hour-to-hour of 10% variability. Besides heating, other or more specific industry heat use option with different demand characteristics e.g. drying in wood and agriculture industries, cooling in food industry may be considered in future [24].

Electricity demand has been calculated as 10.5 MWh/a per household, resulting in total community demand of 13 MWh/d, of which 12 MWh/day have been assumed as primary (nondeferable) load and 1 MWh/day deferrable load. The deferrable load has been considered as max 700 MW and with ability to "store" max 6,000 kWh.

Generators. For the PV array lifetime of 15 years, derating factor of 80%, slope of 32 degrees have been assumed. The capital costs per of 740€/kW are assumed, replacement of 400€/kW and O&M cost of 15€/kW*year.

Solar resource inputs per month are given in the Table 1 in average of 3.47 kWh/m^2*day. For the wind turbine (S3.7) a lifetime of 20 years, hub height of 33.5m, with rated power of 1.8 kW with capital and replacement costs of 3,000€, and O&M costs of 30€/year per turbine are assumed.
The wind resource per month are given in the Table 1 in yearly average of 3.6 m/s.

Table 1 Solar and wind resource inputs

Month	Clearness Index	Daily Radiation (kWh/m^2/d)	Wind Speed (m/s)
January	0.410	1.310	5.319
February	0.482	2.240	2.890
March	0.473	3.220	3.209
April	0.466	4.250	2.998
May	0.487	5.280	3.041
June	0.492	5.700	2.141
July	0.515	5.770	3.123
August	0.525	5.120	3.492
September	0.498	3.780	2.539
October	0.463	2.440	3.992
November	0.393	1.380	5.841
December	0.375	1.040	4.590

For the natural gas CHP plant (NGCHP) a 60,000 working hours lifetime, with minimal load ratio of 30%, with heat recovery ratio of 70% are assumed. The costs of NGCHP for a different sizes are given in Table 2.

Table 2 Natural gas and biogas CHP costs

		Natural gas			Biogas		
	Size (kW)	Capital (€)	Replacement (€)	O&M (€/hr)	Capital (€)	Replacement (€)	O&M (€/hr)
1	75	81,337	81,337	0.01	661,652.00	661,652.00	0.035
2	150	138,654	138,654	0.01	1,039,684.00	1,039,684.00	0.035
3	250	205,421	205,421	0.01	1,450,597.00	1,450,597.00	0.035
4	500	350,177	350,177	0.01	2,279,388.00	2,279,388.00	0.025
5	1,000	596,939	596,939	0.01	3,581,705.00	3,581,705.00	0.025
6	2,000	1,017,589	1,017,589	0.006	5,628,095.00	5,628,095.00	0.025
7	3,000	1,390,191	1,390,191	0.006	7,331,163.00	7,331,163.00	0.013
8	5,000	2,059,621	2,059,621	0.006	10,228,649.00	10,228,649.00	0.013

Assumed efficiency curves of the natural gas and biogas plant for the different levels of load are shown at Fig 2.

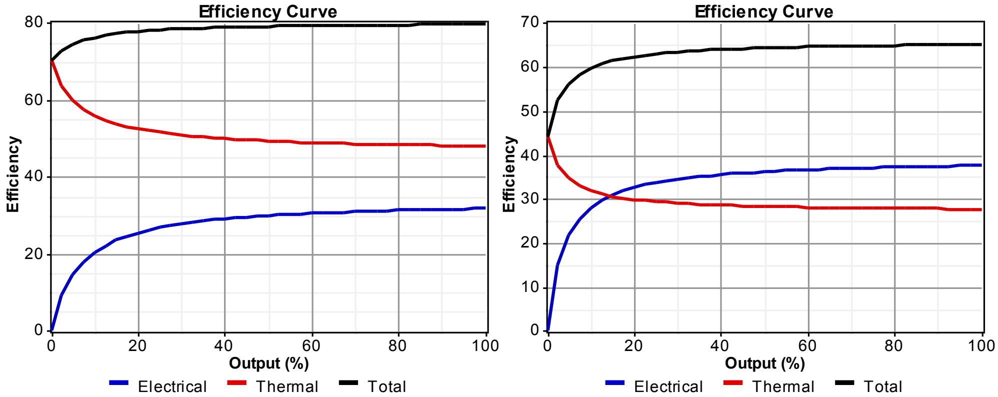

Figure 2 Natural gas (left) and biogas (right) CHP efficiency curve

Assumed maximal overall efficiency of NGCHP plant at nominal output operation is around 80%

For the biogas CHP plant (BGCHP) a lifetime of 60,000 working hours, minimal load ratio of 30%, heat recovery ratio of 44% have been assumed. The typical costs for different sizes of biogas CHP plant (including engine and all facilities costs) are also given in Table 2.

Capital and replacement cost are same for the purpose of simplicity. O&M specific costs are decreasing with the plant size.

Assumed efficiency curve for the BGCHP plant is lower assuming parasite heat (30%) and power consumption (8%) of the digester [22], has been also shown at Fig. 2. The data from the biogas plants in operation from [43] are used to calibrate feedstock consumption for biogas production and realistic electricity and heat production. Heat demand of the digester might be modelled in more detail as a separate heat demand with seasonal effect [24]. Process related details for biogas plants size 75-500 kW_{el} may be found in [18].

The maximal overall energy efficiency of the BGCHP plant is around 65% at nominal output. Besides the modelled CHP plant based on engine, gas turbine [44] may be also considered for in future techno-economic studies.
Optimization search space among different generators and different sizes has been shown at Table 3.

Table 3 HOMER optimization search space (PV Array - photovoltaic array, S3.7 - wind turbine, NGCHP - natural gas CHP, BGCHP - biogas CHP, Grid - national electricity grid connection

	PV Array (kW)	S3.7 (Quantity)	NGCHP (kW)	BGCHP (kW)	Grid (kW)
1	-	-	-	-	1,000
2	250	10	75	75	
3	500	25	150	150	
4			250	250	
5			500	500	
6			1,000	1,000	
7			1,500	1,500	

The total number of possible system designs is 3*3*7*7 = 441. Although usage of continuous variables is possible in optimization, the discrete decision variables are inherent feature of Homer tool. For the improvement of accuracy one may decide to use more decision variables around an optimal point or to repeat procedure, but this should be traded with computation time.

Energy carriers and their prices. The national electricity grid real-time price with an average 3,5 and 10 c€/kWh has been assumed. The hourly price is dependable on wholesale electricity market prices. The power density function for the average price of 5 c€/kWh has been shown at Fig. 3. For other prices power density function has been translated over price axis assuming same distribution.

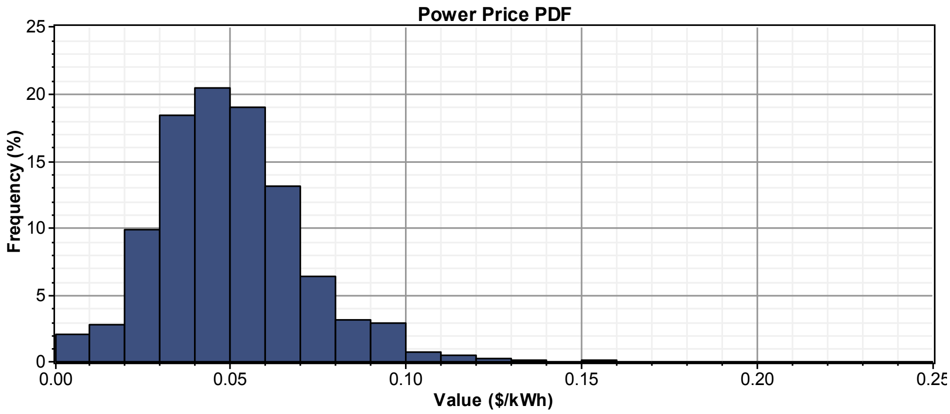

Figure 3 Power density function of the national electricity grid hourly price.

For the natural gas lower heating value of 45 MJ/kg, density of 0.79 kg/m3 , carbon content of 67% and sulphur content of 0.33% have been assumed. For the biogas a daily average of 1,000 t of manure and organic waste input has been assumed. Assumed gasification ratio is 0.5 kg of gas/kg feedstock, lower heating value of biogas 18.5 MJ/kg and carbon content of 38% have been assumed. Detailed methane production from different feedstock types may be considered in future [24]. Maximal manure feedstock costs for a different feed in support should not exceed 3-7€/t [15]. Farm distance to the biogas CHP plant and different ownership models: third party and farmers bring different economics. Additionally this economics might modelled as the increase in the price of feedstock [15], even in more detail using GIS tools [45].

The sensitivity analysis search space of the prices of natural gas and subvention feedstock are given in the Table 4.

Table 4 Sensitivity inputs space

	Biomass (€/t)	Natural gas (€/Nm3)
1	-10	0.1
2	-5	0.2
3	0	0.3
4	5	0.4
5	10	0.5

The search space for sensitivity analysis consists of 5*5 =25 options. Together with 441 possible system design options, creates a 11,025 yearly simulations to run during the optimization.

The grid purchase/sale capacity of 1,000 kW has been assumed.

For the economic situation, annual real interest rate of 5%, project lifetime of 30 years have been assumed.

The overall biogas production potential in the Republic of Serbia has been estimated [46] but up to day no exact details on City of Sabac exist. Based on the first assessment the availability of the feedstock from animal manure for the City of Sabac and the Macva district has been given in the Table 5. This assessment has to be done with more detail including also other different feedstock and their biogas yield detail [18], as well as other available sources of dry biomass [47].

Table 5 Available feedstock for biogas production from manure in the Macva state district and City of Sabac.

Area/Type	Catle	Pigs	Sheep	Poultry	Σ Feedstock [t/d]
Macva state district	80,283	400,391	161,878	1,060,996	3,591
City of Sabac	26,837	116,881	36,233	289,520	1,117

For the biomass resource inputs a constant annual availability of the feedstock at 1,000 t/d has been assumed for the first case, but it in future more realistic assumption, due to availability and possibility of seasonal scheduling, should be accessed.

RESULTS

The optimal system structure graph as a result of HOMER simulations of sensitivity variables (natural gas price and biomass price) has been shown at Fig. 4-6 for differently assumed national grid electricity price, according to the wholesale market price. Additionally levelized cost of energy for the municipal grid customers (€/kWh) has been superimposed.

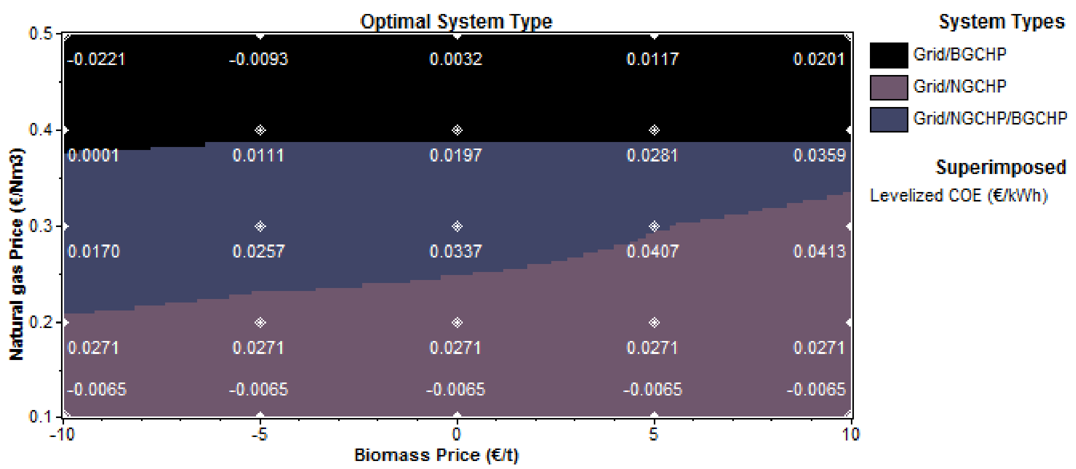

Figure 4 Optimal system structure for national electricity grid average price of 5c€/kWh.

For the average national grid electricity price of 5c€/kWh, three (3) optimal system structures are viable:

1. combination of national electricity grid with natural gas generator (Grid/NGCHP),
2. combination of national electricity grid with biogas generator (Grid/BGCHP) and

3. national electricity grid with natural gas generator and with biogas generator (Grid/NGCHP/BGCHP).

Natural CHP in combination with national electricity grid is optimal system structure for the natural gas price of 0.2 €/Nm3, and up to 0.4 €/Nm3 depending on the price of biomass, lower area of the graph. The negative levelized cost of the energy in the case of extremely low natural gas prices of 0.1 €/Nm3 shows profitable to sell electricity from the NGCHP to the national grid, while in the case of 0.2 €/Nm3 it may decrease electricity the price under the average national grid price. The upper triangle of the space defined with moderate natural gas prices 0.2-0.4 €/Nm3 shows optimal to build BGCHP besides a NGCHP, while for the prices above 0.4 €/Nm3 NGCHP is not profitable. The levelized costs of energy in all cases are below the national grid average price.

Calculated marginal cost of heat from BGCHP is 0.5 c€/kWh and for NGCHP is 9 c€/kWh in the [0.3 €/Nm3, 5 €/t] scenario. These marginal cost are calculated based on the capacity factors obtained during the simulation, 72% for BGCHP and 25% for the NGCHP.

For the average national grid electricity price of 3c€/kWh, Fig. 5., three (3) optimal system structures are viable:

1. national electricity grid (Grid),
2. combination of national electricity grid with natural gas generator (Grid/NGCHP)
3. combination of national electricity grid with biogas generator (Grid/BGCHP).

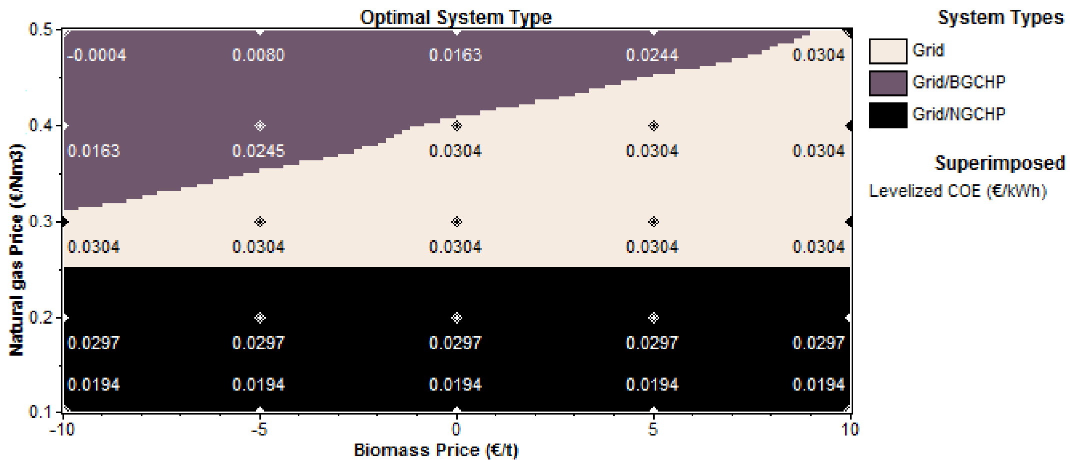

Figure 5 Optimal system structure for national electricity grid average price of 3c€/kWh.

The decreased national electricity grid average price for 0.2 c€/kWh resulted in national grid become one of the optimal system types within natural gas price 0.25-0.5 €/Nm3 depending on the biomass price, middle triangle of the graph. The construction of BGCHP is advised for the natural gas price above 0.3 €/Nm3 in the case of subsidised biogas or above natural gas price of 0.4 €/Nm3 and 0.5 €/Nm3 for the higher biomass prices, upper triangle. Below the natural gas price of 0.25 €/Nm3 the combination of national grid and NGCHP is optimal, lower rectangle. The levelized costs of energy could be decreased based on the construction of NGCHP or BGCHP.

For the average national grid electricity price of 10c€/kWh, Fig. 6., the eight (8) optimal system structures are viable:

1. combination of national electricity grid with natural gas generator (Grid/NGCHP),

2. combination of national electricity grid with natural gas and biogas generator (Grid/NGCHP/BGCHP),
3. combination of national electricity grid with PV and natural generator (Grid/PV/NGCHP),
4. combination of national electricity grid with PV, natural and biogas generator (Grid/PV/NGCHP/BGCHP),
5. combination of national electricity grid with wind and natural gas generator (Grid/Wind/NGCHP)
6. combination of national electricity grid with wind, natural gas and biogas generator (Grid/Wind/NGCHP/BGCHP),
7. combination of national electricity grid with PV, wind and natural gas generator (Grid/PV/Wind/NGCHP) and
8. combination of national electricity grid with PV, wind, natural and biogas generator (Grid/PV/Wind/NGCHP/BGCHP).

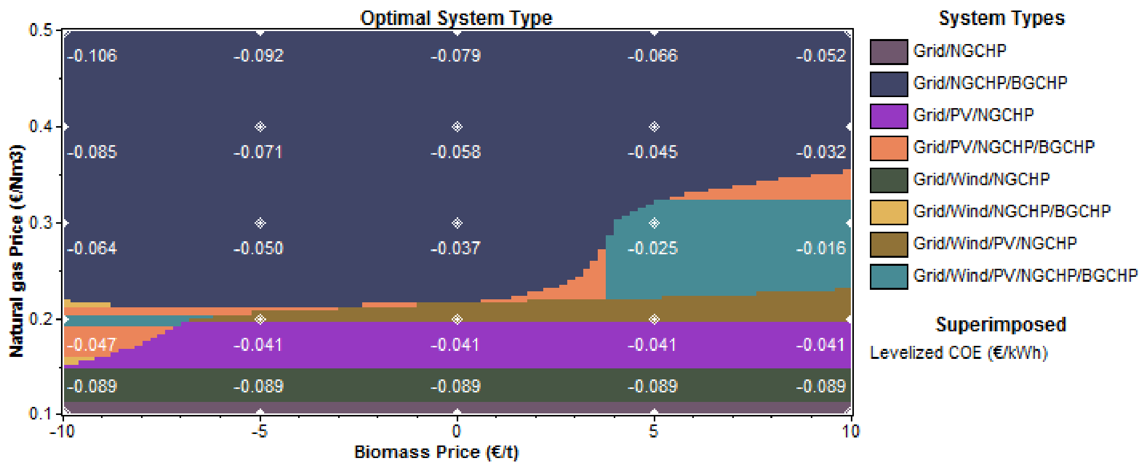

Figure 6 Optimal system structure for national electricity grid average price of 10c€/kWh.

Starting from natural gas price of 0.1 €/Nm3 for all biomass prices combination of national electricity grid with natural gas generator (Grid/NGCHP) is optimal system structure, followed with combination of national electricity grid with wind and natural gas generator (Grid/Wind/NGCHP) first, and combination of national electricity grid with PV and biogas generator (Grid/PV/BGCHP) as optimal system structure later until natural gas price reaches 0.2 €/m3. Until natural gas price of 0.35 €/Nm3 is still competitive in three system combinations: combination of national electricity grid with PV, wind and natural gas generator (Grid/PV/Wind/NGCHP) shown at the right lower triangle, combination of national electricity grid with natural gas and biogas generator (Grid/NGCHP/BGCHP) and combination of national electricity grid with PV, natural and biogas generator (Grid/PV/NGCHP/BGCHP). Above 0.35 €/Nm3 natural gas and biogas generators are competing, differently sized for different price combinations.

For the national electricity grid average price of 10c€/kWh and higher all design cases are profitable because levelized cost of energy are negative.

Rate of return

Economics of the different system configurations for the national electricity grid average price of 5c€/kWh are shown in Table 6.

Table 6 Economics comparison of different system configurations with base configuration for the 5c€/kWhel average price and four combinations of biomass and natural gas prices.

System characteristics	Base	S1	S2	S3	S4	S5
Biomass [€/t]		-10	-5	0	5	10
Natural gas [€/Nm3]				0.3		
NGCHP [kW]	-	500	500	500	500	1,000
BGCHP [kW]	-	1,000	1,000	1,000	1,000	-
Grid [kW]	1,000	1,000	1,000	1,000	1,000	1,000
Initial cost [€]	-	3,931,882	3,931,882	3,931,882	3,931,882	596,939
Total cost [€]	11,592,836	9,133,686	9,763,992	10,350,609	10,861,921	10,902,640
Present worth [€]		2,459,154	1,828,847	1,242,229	730,917	690,197
Annual worth [€/year]		159,971	118,969	80,809	47,547	44,898
Return on investment [%]		10.40%	9.41%	8.45%	7.56%	13.9%
Internal rate of return [%]		11.10%	9.58%	8.15%	6.87%	15.3%
Simple payback [years]		5.16	5.62	6.19	7.04	5.63
Discounted payback [years]		6.13	6.77	7.6	8.9	6.78
Hours NGCHP	-	2,410	2,410	2,410	2,410	4,327
Hours BGCHP	-	7,849	7,484	7,031	6,331	-

First two rows are assumed biomass and natural gas prices. The next three rows are resulting optimal system structures for the assumed prices. The base system, used for all comparisons is consisted of only connection to the national electricity grid (Grid). Other scenarios (S1-5) are:

- combination of national electricity grid with natural gas generator (Grid/NGCHP) and
- combination of national electricity grid with natural gas and biogas generator (Grid/NGCHP/BGCHP).

The selected sizes of biogas generators are 1,000 kW and 500 kW for the natural gas generators. Sixth row presents initial costs, which are capital investment costs (CAPEX) for the equipment. Assuming that grid exist the investment cost for the grid are zero. The total cost, sum of the CAPEX and operation costs (OPEX) over the project lifetime, are shown lower in scenarios S1-5 than in base scenario. This resulting in return of investment 7.56-10.4% for the Grid/NGCHP/BGCHP system structure and 13.9% for Grid/NGCHP system structure. The discounted payback is 6.13-8.9 years, showing that it is sensitive to the economic subsidies for biomass. Further calculations may show a desired level of subsidy for biomass.

Hours of operation

The realistic hours of operation for NGCHP and BGCHP plants, obtained from 8,760 hourly simulations over one year are shown at last two rows of the Table 8. The capacity factor of the profitable BGCHP plant is 0.7-0.9 if used, and 0.25-0.5 for the NGCHP plant. They are not constant but rather dependable on many system design factors. At the breakpoints the hours of operation of one generator structure suddenly may drop to zero resulting in jumping of the hours of operation of other generator types. Further analysis may show that BGCHP plant is profitable only in the higher hours of operation than NGCHP plant.

CONCLUSION

In this article it has been shown that smart municipal grids could decrease levelized cost of energy in the municipal grid below national electricity grid average price based on their flexibility.

The payback periods of the smart municipal grids may be decreased with a properly designed economic support energy policy.

Hours of operation of CHP plant are dependable on many system design factors and may not be assumed exogenous, and kept at constant level in the techno-economics feasibility study during the investment decision.

ACKOWLEDGEMENTS

The authors are acknowledge the support from the "CoolHeating" Horizon 2020 project from European Commission grant nr. 691679. The first two authors are thankful to the Ministry of Education, Science and Technological development on the grant nr. 42009/11 for the "Smart grids".

REFERENCES

[1] C. Mitchell, "Momentum is increasing towards a flexible electricity system based on renewables," *Nature Energy,* vol. 1, p. 15030, 2016.

[2] N. Blaauwbroek, P. H. Nguyen, M. J. Konsman, S. Huaizhou, R. I. G. Kamphuis, and W. L. Kling, "Decentralized Resource Allocation and Load Scheduling for Multicommodity Smart Energy Systems," *Sustainable Energy, IEEE Transactions on,* vol. 6, pp. 1506-1514, 2015.

[3] T. Capuder and P. Mancarella, "Techno-economic and environmental modelling and optimization of flexible distributed multi-generation options," *Energy,* vol. 71, pp. 516-533, Jul 15 2014.

[4] I. Batas Bjelić, N. Rajaković, B. Ćosić, and N. Duić, "Increasing wind power penetration into the existing Serbian energy system," *Energy,* vol. 57, pp. 30-37, 2013.

[5] F. Shariatzadeh, P. Mandal, and A. K. Srivastava, "Demand response for sustainable energy systems: A review, application and implementation strategy," *Renewable and Sustainable Energy Reviews,* vol. 45, pp. 343-350, 2015.

[6] P. Roudier, J. C. M. Andersson, C. Donnelly, L. Feyen, W. Greuell, and F. Ludwig, "Projections of future floods and hydrological droughts in Europe under a +2°C global warming," *Climatic Change,* pp. 1-15, 2015.

[7] C. Chen, J. Wang, F. Qiu, and D. Zhao, "Resilient Distribution System by Microgrids Formation After Natural Disasters," *IEEE Transactions on Smart Grid,* vol. 7, pp. 958-966, 2016.

[8] L. Montuori, M. Alcázar-Ortega, C. Álvarez-Bel, and A. Domijan, "Integration of renewable energy in microgrids coordinated with demand response resources: Economic evaluation of a biomass gasification plant by Homer Simulator," *Applied Energy,* vol. 132, pp. 15-22, 2014.

[9] M. B. Blarke, "Towards an intermittency-friendly energy system: Comparing electric boilers and heat pumps in distributed cogeneration," *Applied Energy,* vol. 91, pp. 349-365, 2012.

[10] I. Batas Bjelic and R. M. Ciric, "Optimal distributed generation planning at a local level – A review of Serbian renewable energy development," *Renewable and Sustainable Energy Reviews,* vol. 39, pp. 79-86, 2014.
[11] D. Thrän, M. Dotzauer, V. Lenz, J. Liebetrau, and A. Ortwein, "Flexible bioenergy supply for balancing fluctuating renewables in the heat and power sector—a review of technologies and concepts," *Energy, Sustainability and Society,* vol. 5, pp. 1-15, 2015.
[12] R. M. Ciric and Z. Kuzmanovic, "Techno-Economic Analysis of Biogas Powered Cogeneration," *Journal of Automation and Control Engineering Vol,* vol. 2, 2014.
[13] A. Krkoleva, V. Taseska, N. Markovska, R. Taleski, and V. Borozan, "Microgrids: The agria test location," *Thermal Science,* vol. 14, pp. 747-758, 2010.
[14] M. M. Stojiljković, M. M. Stojiljković, B. D. Blagojević, G. D. Vučković, and M. G. Ignjatović, "Effects of implementation of co-generation in the district heating system of the Faculty of Mechanical Engineering in Niš," *Thermal Science,* vol. 14, pp. 41-51, 2010.
[15] T. Puksec and N. Duic, "Economic viability and geographic distribution of centralized biogas plants: case study Croatia," *Clean Technologies and Environmental Policy,* vol. 14, pp. 427-433, Jun 2012.
[16] D. Dominković, B. Ćosić, Z. B. Medić, and N. Duić, "A hybrid optimization model of biomass trigeneration system combined with pit thermal energy storage," *Energy Conversion and Management,* 2015.
[17] T. Mitschke. (2015). *Small Scale Slurry Biogas Plants for medium-sized farms in Serbia as an additional income source*.
[18] FNR, *Guide to Biogas: From Production to Use*: Fachagentur Nachwachsende Rohstoffe 2012.
[19] S. M. Cvetković, T. S. Kaluđerović-Radoičić, R. B. Kragić, and M. L. Kijevčanin, "Electricity production from biogas in Serbia-assessment of emissions reduction," *Thermal Science,* pp. 189-189, 2015.
[20] V. Vukašinović, M. Babić, D. Gordić, D. Jelić, and D. Končalović, "Pregled dostupnih modela gasnih turbina i motora sa unutrašnjim sagorevanjem koji se mogu koristiti u kogeneracionim sistemima.," *Energija, ekonomija, ekologija,* vol. 15, pp. 265-278, 2013.
[21] A. Wellinger, J. Murphy, and D. Baxter, *The Biogas Handbook: Science, Production and Applications*: Woodhead Pub Limited, 2013.
[22] M. Köttner and K. Kayser, "Assessment of the framework conditions for biogas production in Serbia," IBBK Fachgruppe Biogas GmbH 2014.
[23] S. A. Gebrezgabher, M. P. M. Meuwissen, B. A. M. Prins, and A. G. J. M. O. Lansink, "Economic analysis of anaerobic digestion—A case of Green power biogas plant in The Netherlands," *NJAS - Wageningen Journal of Life Sciences,* vol. 57, pp. 109-115, 2010.
[24] D. Rutz, R. Mergner, and R. Janssen, "Sustainable Heat Use of Biogas Plants," *A Handbook, Biogas Heat, WIP Renewable Energies, Munich, Germany,* 2012.
[25] J. Murphy, R. Braun, P. Weiland, and A. Wellinger, "Biogas from energy crop digestion," 2010.
[26] DEA. (2010). *Technology Data for Energy Plants*. Available: http://www.ens.dk/sites/ens.dk/files/dokumenter/publikationer/downloads/technology_data_for_energy_plants.pdf
[27] ***. (2012). *Draft National Renewable Energy Action Plan*. Available: https://www.energy-community.org/pls/portal/docs/2144185.PDF
[28] S. Ghaem Sigarchian, R. Paleta, A. Malmquist, and A. Pina, "Feasibility study of using a biogas engine as backup in a decentralized hybrid (PV/wind/battery) power generation system – Case study Kenya," *Energy,* vol. 90, Part 2, pp. 1830-1841, 2015.

[29] D. Connolly, H. Lund, B. V. Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Applied Energy,* vol. 87, pp. 1059-1082, 2010.
[30] T. Lambert, P. Gilman, and P. Lilienthal, "Micropower System Modeling with Homer," in *Integration of alternative sources of energy*, ed: John Wiley & Sons, Inc., 2006, pp. 379-418.
[31] O. Chowdhury, H.-g. Kim, Y. Cho, C. Shin, and J. Park, "Optimization of a Hybrid Renewable Energy System with HOMER," in *Advances in Computer Science and Ubiquitous Computing*. vol. 373, D.-S. Park, H.-C. Chao, Y.-S. Jeong, and J. J. Park, Eds., ed: Springer Singapore, 2015, pp. 93-99.
[32] M. Corrand, S. J. Duncan, and D. N. Mavris, "Incorporating Electrical Distribution Network Structure into Energy Portfolio Optimization for an Isolated Grid," *Procedia Computer Science,* vol. 16, pp. 757-766, 2013.
[33] T. M. Weis and A. Ilinca, "The utility of energy storage to improve the economics of wind–diesel power plants in Canada," *Renewable Energy,* vol. 33, pp. 1544-1557, 2008.
[34] D. Neves, A. Pina, and C. A. Silva, "Demand response modeling: A comparison between tools," *Applied Energy,* vol. 146, pp. 288-297, May 15 2015.
[35] M. R. Basir Khan, R. Jidin, J. Pasupuleti, and S. A. Shaaya, "Optimal combination of solar, wind, micro-hydro and diesel systems based on actual seasonal load profiles for a resort island in the South China Sea," *Energy,* vol. 82, pp. 80-97, 2015.
[36] O. Hafez and K. Bhattacharya, "Optimal planning and design of a renewable energy based supply system for microgrids," *Renewable Energy,* vol. 45, pp. 7-15, 2012.
[37] H. Rui, S. H. Low, T. Ufuk, K. M. Chandy, and C. R. Clarke, "Optimal design of hybrid energy system with PV/wind turbine/storage: A case study," in *Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference on*, 2011, pp. 511-516.
[38] E. D. Giannoulis and D. A. Haralambopoulos, "Distributed Generation in an isolated grid: Methodology of case study for Lesvos – Greece," *Applied Energy,* vol. 88, pp. 2530-2540, 2011.
[39] A. Al-Karaghouli and L. L. Kazmerski, "Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software," *Solar Energy,* vol. 84, pp. 710-714, 2010.
[40] I. R. Batas Bjelić, I. A. Škokljev, T. Pukšec, G. Krajačić, and N. Duić, "Integrating the flexibility of the average Serbian consumer as a virtual storage option into the planning of energy systems," *Thermal Science,* vol. 18, pp. 743-754, 2014.
[41] F. A. Canales and A. Beluco, "Modeling pumped hydro storage with the micropower optimization model (HOMER)," *Journal of Renewable and Sustainable Energy,* vol. 6, p. 043131, 2014.
[42] Č. Zeljković and N. Rajaković, "Cost-saving potential of customer-driven distributed generation," *Electric Power Systems Research,* vol. 92, pp. 87-95, 2012.
[43] D. Djatkov, M. Effenberger, A. Lehner, M. Martinov, M. Tesic, and A. Gronauer, "New method for assessing the performance of agricultural biogas plants," *Renewable Energy,* vol. 40, pp. 104-112, 2012.
[44] J. Y. Kang, D. W. Kang, T. S. Kim, and K. B. Hur, "Comparative economic analysis of gas turbine-based power generation and combined heat and power systems using biogas fuel," *Energy,* vol. 67, pp. 309-318, 2014.
[45] C. Konrad, J. Strittmatter, A. Grunert, M. Brule, M. Roth, M. Herter, G. Göttlicher, R. Biehl, and A. Bott, "Regional energy concepts-based on alternative biomass cultivation for rural areas and its efficient energy usage," *International Journal of Sustainable Development and Planning,* vol. 8, pp. 59-74, 2013.

[46] S. Cvetković, T. Kaluđerović Radoičić, B. Vukadinović, and M. Kijevčanin, "Potentials and status of biogas as energy source in the Republic of Serbia," *Renewable and Sustainable Energy Reviews,* vol. 31, pp. 407-416, 2014.
[47] L. Eltrop, M. Hertlajn, T. Jensen, M. Hensler, K. Kruk, E. D. Ezdemir, H. Hartman, N. Pobos, and G. Šefkneht, "Priručnik o čvrstim biogorivima," Beograd2014.